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Transitioning the Sugarcane Industry to the Circular Economy in Central America. Can it lead the transformation in the food sector?

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Abstract

The sugar industry is one of the leading economic sectors in Central America, as demonstrated by the industry's output volume, labor utilization, and biomass energy use, all among the most significant in regional economic activity. At the same time, the industry imposes a heavy burden on Central American societies: it requires extensive land use, heavy use of nitrogen-based fertilizers, large amounts of water, and the emissions resulting from the industrial processes are a considerable source of pollution.

The sugarcane industry's current production cycles and machinery (the sugarcane mill being the most emblematic) were developed during the 19th century. Therefore, the industry follows a classic linear production workflow whereby it relies on significant asset investments that cannot be easily adapted to another industrial process; the main goal is usually to maximize production every harvest season disregarding the externalities. How can, then, this sector transforms this anachronistic industrial method to adapt to a framework of circular economic development? This paper analyzes current industrial trends and processes among leading sugar producers in Central América. We use Life Cycle Assessment (LCA) methodology to evaluate an archetypal sugar mill and develop a simulated model of the environmental impacts of the industry using SimaPro software and the International Reference Life Cycle Data System (ILCD) method; the results are applied to estimate sugar production and visualize the impact characterization. Finally, a circular economy framework is used to develop guidelines for transition to a sustainable production model in the sugar sector.

The results demonstrate that the Central American sugar industry can indeed become a key player in sustainable development if circular economy concepts are understood and implemented in the production process. We also identify barriers and challenges in the current production model that need to be addressed before this transformation takes place.

Keywords: *Circular Economy, Central America, food production, LCA*

1. Introduction

Sugarcane was introduced in Central America during the 16th century (The Sugar Association 2020). It played a significant role in the colonial economy; slave labor and fertile soils quickly turned sugarcane production into one of the most profitable colonial enterprises. Currently, the industry still benefits from the edaphoclimatic conditions and cheap labor, and it is still playing a significant role in the GDP outputs in the region. Central American sugar is now a traded commodity, however, and global competition has lowered the price—coupled with a reduction in sugar content in the diet in developed countries—reducing profit margins for producers and exporters. Historically, sugarcane production has been an artisanal affair, but during the 19th and 20th centuries, more complex and technical facilities were developed in order to increase milling capacity and to improve production yields; due to the large startup investment, large landowners with extensive economic resources were the leading investors in the industry's development stage. As a result, sugar production in central America, up to the present, is controlled by some of the historically wealthiest families.

Sugarcane plantation yields may range from 50 metric tons per hectare (t/ha) up to 200 tons per hectare (Rein 2007). Sugarcane is quite sensitive to weather conditions; thus, crops must be highly adaptable. In Centra America, harvesting and processing seasons follow the rainy season (once per year); therefore, there is only one harvest per year, called the Zafra, which in central America takes place from October or November to March or April. The facilities where sugarcane is milled and processed are called ingenios and are generally located in the countryside, near plantations, and water resources. In central America, sugarcane yields can range from 30t/ha (with poor crop drought conditions) up to 140t/ha (using a combination of nitrogen-based fertilizers, agrochemicals, and irrigation systems).[1](Asociación Azucarera Salvadoreña 2020; Azúcar de Guatemala 2020; Comité Nacional de Productores de Azúcar de Nicaragua 2020; Asociación de Productores de Azúcar de Honduras 2020; Liga Agrícola Industrial de la Caña de Azúcar de Costa Rica 2020; CEPAL 2018) At the same time, mill yields can range from 50kg to 130 kg of raw sugar per ton of harvested sugarcane. The importance of sugarcane as a significant export commodity can be seen in Table 1, which shows that sugarcane represents a significant percentage of the countries' GDP:

Table 1: Sugar production as GDP percentage per country

Country	GDP (US Millions)	Sugar industry contribution to GDP in 2018 (US Millions)	% of GDP
Guatemala	78,461	1,412	1.80%
El Salvador	26,057	704	2.70%
Honduras	23,970	288	1.20%
Nicaragua	13,118	273	2.80%
Costa Rica	60,126	n/a	n/a
Panamá	65,055	n/a	n/a

Source: adapted from ("National Accounts - Analysis of Main Aggregates (AMA)" n.d.; Banco Central de Honduras 2020; "Banco Central de Reserva de El Salvador -" 2020; Banco Central de Nicaragua 2020; Banco Central de Guatemala 2020; CEPAL 2018)

Overall, sugarcane production has fluctuated, tending to increase over time, but externalities such as hurricanes, droughts and climate disasters have taken a toll on yields in the last decade.

Table 2: Trend of sugar cane production from 2009 to 2016

Country	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016
Guatemala	3734.7	3418.2	4005.8	4411.1	4344	4265.9	4158.4
El Salvador	5126.7	5832	6487.4	7163	6782.8	6578.5	7202.1
Honduras	22313.8	20586.1	24289.9	26913.6	33239	33869	33533
Nicaragua	6490.6	5724.6	5860.5	5150.7	5391.1	5170.8	5355.7
Costa Rica	4893.9	5442.6	6732.3	6728.1	6997.6	6375.6	6815.1
Panamá	2229	2263.9	2275.6	2482.2	2380.8	2380.8	2419.6
Total:	44788.7	43267.4	49651.5	52848.7	59135.3	58640.6	59483.9

Source: Adapted from (CEPAL 2018)

In Central America, sugar cane producers are organized in powerful trade associations. According to these associations the sugar industry provides several benefits to local countries such as work opportunities for low-skilled laborers, since the maintenance and harvest of the crop is mostly a manual operation; in addition, the sector claims to employ more than 990,000 people per *zafra* in Central América, through a combination of seasonal and hired labor .

Until recently, the industry has been heavily criticized for its reliance on child labor; this situation has changed mostly due restrictions imposed by outside industrial contractors and suppliers, forcing the industry to enact restrictions on the use of child labor.

Almost all sugar associations in Central America claim to support the Sustainable Developing Goals (SDGs) (United Nations 2020), and since their crops use a combination of fossil and renewable energy sources, the sugarcane industry frequently claims clean, renewable-energy industry. This paper analyzes the role of the sugar industry as a potential key player in efforts to reach the SDGs in Central America from two perspectives: by first analyzing the production process from a life cycle perspective and, secondly, by contrasting it to a circular economy framework to determine potential pathways of transformation.

2. Context

2.1. Current Production Process

Sugarcane production relies on complex facilities with fixed machinery. The production process is a mixture of seasonal production and batch, line production. The production can be divided into two main areas: the sugarcane crop and harvest process and the sugarcane milling process. Figure 1 presents a life cycle schema of the sugarcane crop and harvest process, including the greenhouse phase, until sugarcane production is ready for the mill. Figure 2 outlines the process from the mill to the sugar refinery facility. Both processes involve several flows that suggest intensive use of resources, either from nature in an intensive form (land and water)—some are indeed renewable, such as the biomass contained in the sugarcane--and some came nonrenewable sources (nitrogen base fertilized and agrochemicals).

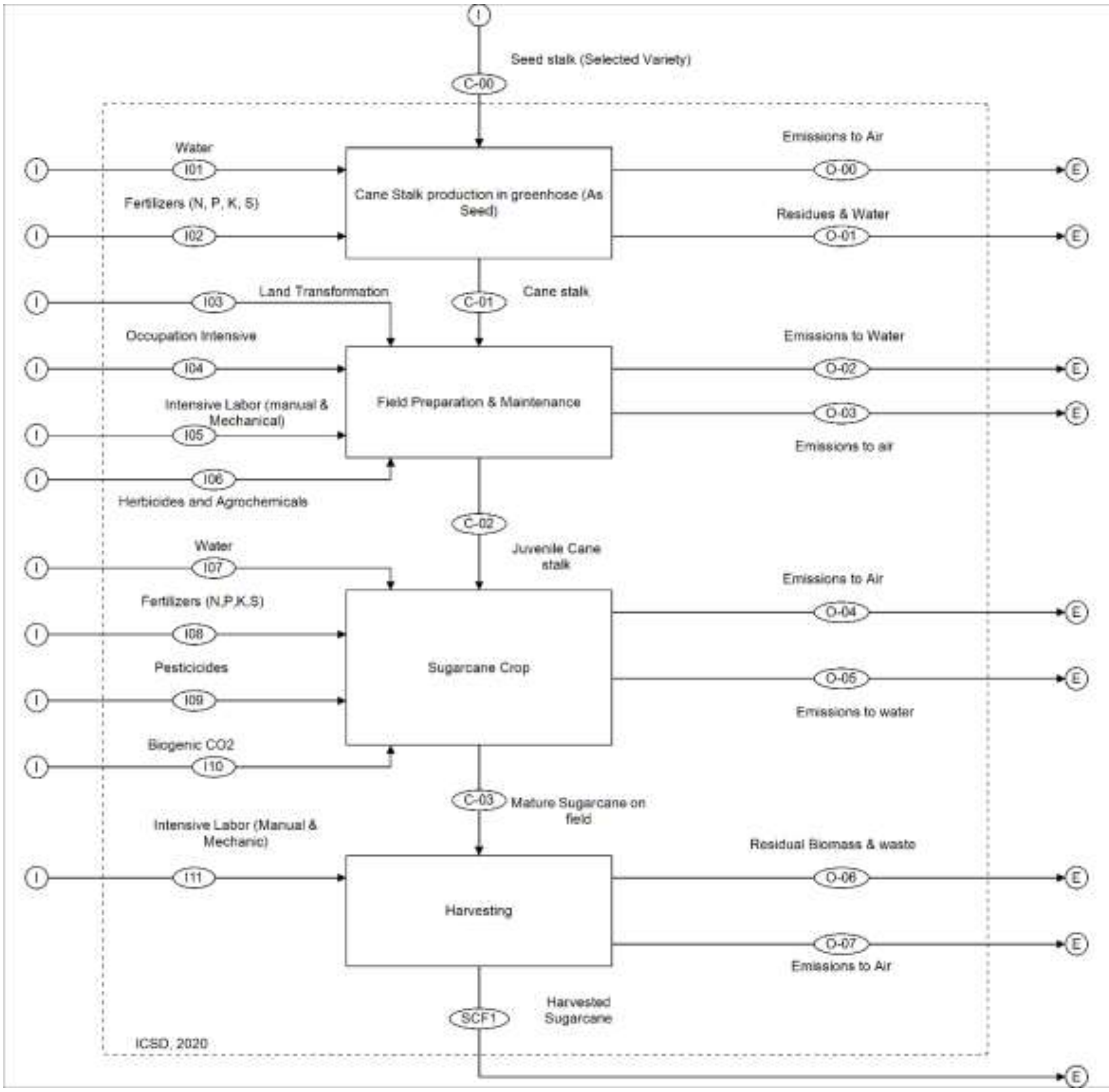

Figure 1: Generic scheme of sugarcane crop and harvest, including the greenhose process. Made by Authors

The sugarcane crop process follows a classic linear flow where, in order to increase output (tons of harvested sugarcane), various enhancers are required, such as nitrogen-based fertilizers, mono-crop intensive occupation of land, and other technical approaches to increase field yield.

Notice that this process does include sequestration of CO2 naturally occurring during the growth of the plant (sugarcane traps carbon to produce the stalk and the sucrose) because this CO2 is re-released through the industrial process in the form of bagasse (dry pulpy residue) used as fuel for the boiler; the amount sequestered by the plant is, in effect, offset with the emissions of the process.

Other intensive resources used (nitrogen-based fertilized, intensive labor) will generate more CO2 emission when analyzed through a Life Cycle Approach, as shown in Table 3:

Table 3: Main Fluxes in the Sugar cane crop & Harvest stage

In		Internal		Out	
C-00	Seed stalk	C-01	Cane Stalk	O-00	Emissions to Air
I01	Water	C-02	Juvenile Cane.	O-01	Residues and water
I02	Fertilizers (N,P,K,S)	C-03	Mature Sugarcane	O-02	Emissions to water
I03	Land Transformation	SCF1	Harvested Sugarcane	O-03	Emissions to Air
I05	Occupation, Intensive			O-04	Emissions to Air
I05	Intensive Labor, Manual			O-05	Emissions to Water
I06	Herbicides and Agrochemical			O-06	Residual Biomass & waste
I07	Water			O-07	Emissions to Air
I08	Fertilizers (N,P,K,S)			SCF1	Harvested Sugarcane
I09	Pesticides				
I10	Biogenic CO_2				
I11	Intensive Labor, Manual				

Various interesting flows are present in the sugarcane production process. For example, all the energy required for the facility's operation comes from the same sugarcane crushed and milled in the facility: the bagasse (residual biomass from the sugarcane) is used as fuel for the boiler. The energy produced inside the mill is generally enough to provide not only all the energy (electricity, heat, and steam) used at the mill. Depending on the technology available and the local regulations, it is sometimes possible to provide energy to the public net.

Besides, most of the chemicals used in the process (sulfur dioxide, lime, flocculants, activated carbon, phosphoric acid) are required to clean, inoculate, clarify, and transform the raw juice into sucrose crystals. However, few chemicals are required for the boiler process, which renders this a relatively clean stage compared to other extensive industrial processes..

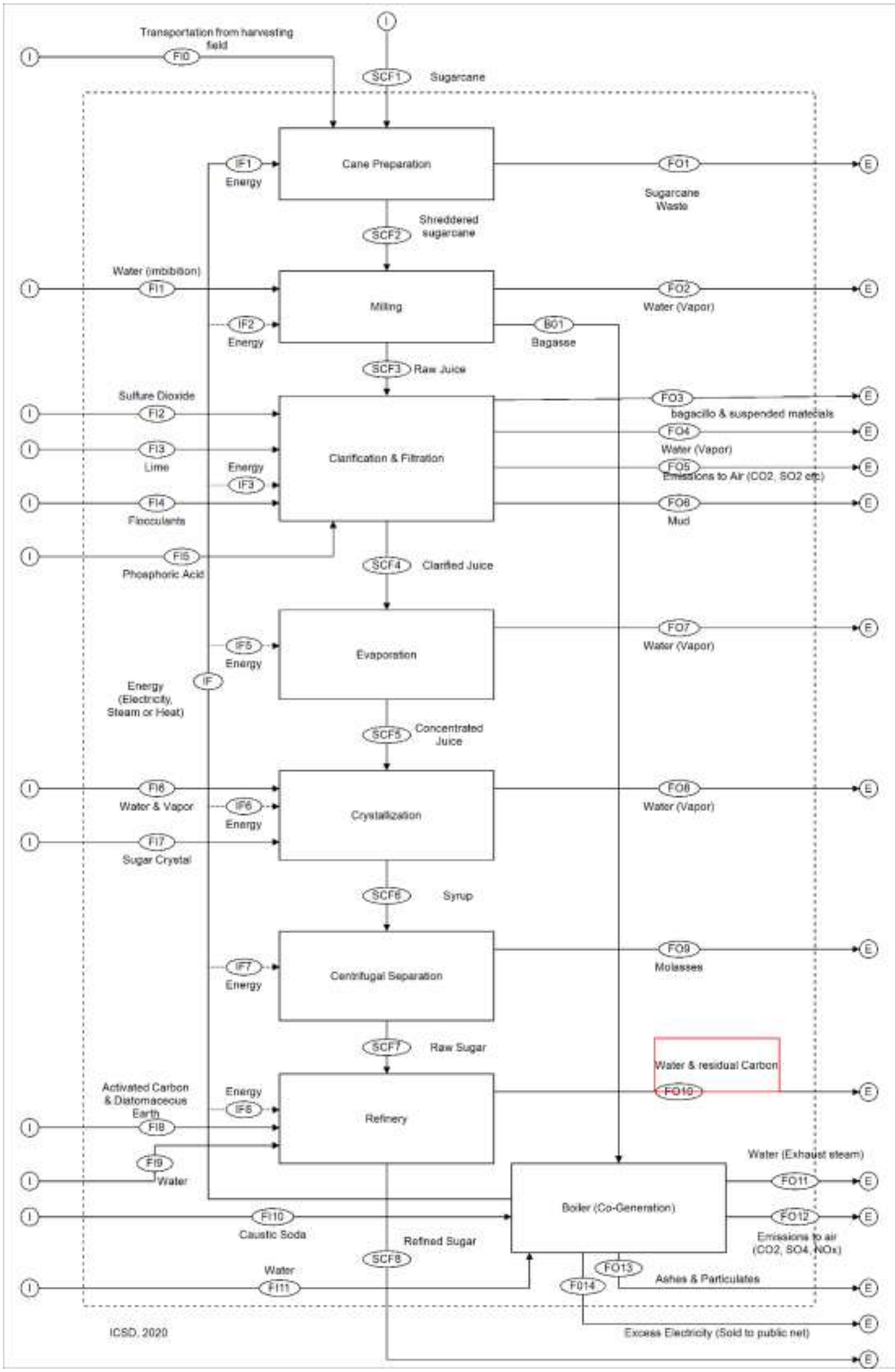

Figure 2: Generic scheme of Sugar mill process, including Refinery and Boiler for co-generation

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Table 4: Main Fluxes in the Sugar mill

In		Internal		Out	
FI0	Transportation	IF01	Energy	FO1	Sugarcane Waste
FI1	Water	IF02	Energy	FO2	Water
FI2	Sulfur Dioxide	IF03	Energy	FO3	Bagacillo & suspended materials
FI3	Lime	IF04	Energy	FO4	Water
FI4	Flocculants	IF05	Energy	FO5	Emissions to Air
FI5	Phosphoric Acid	IF06	Energy	FO6	Mud
FI6	Water	IF07	Energy	FO7	Water
FI7	Sugar Crystal	IF08	Energy	FO8	Water
FI8	Activated Carbon	SCF2	Shredded sugarcane	FO9	Molasses
FI9	Water	SCF3	Raw juice	FO10	Water & residual carbon
FI10	Caustic Soda	SCF4	Clarified Juice	FO11	Water
FI11	Water	SCF5	Concentrated Juice	FO12	Emissions to Air
SCF1	Harvested Sugarcane	SCF6	Syrup	FO13	Ashes & particulates
		SCF7	Raw Sugar	FO14	Excess Electricity to grid
		SCF8	Refined Sugar		

2.2. The need for more sustainable approaches

Sugarcane production relays on massive asset facilities. The production process is a mixture of seasonal production with batch /line production. As noted in figures 1 & 2, the demand for energy sources motivated the use of bagasse as a biomass fuel source. The advances in technology allowed the use of more efficient boilers and turbines. Nowadays, most of the sugar mill facilities in central America are energy self-sustained and can supply energy to the public energy network with the remaining energy generated. This indeed contributes to the reduction of the carbon footprint, since in central America, energy from biomass has priority over other thermal sources (such as fossil fuel generators). The Zafra season is also very convenient since the end of the harvest season. The Zafra is generally at the end of the dry season (where other sources of energy such as hydroelectric, are in their lower levels). In the end, a combination of income, the energy produced, and labor generated are presented as the main benefits for the sugar industry, as shown in Table 5.

Table 5: Productions reported by central American sugar mills for Zafra 2019-2020

Country	SugarMill	Crop Size (Ha)	Sugar Produced (Tons)	Energy Produced (KW)	Labour generated (direct & indirect)
Guatemala	11	297,000	2,900,000	933,000	336,000
El Salvador	6	80,000	750,000	425,000	235,000
Honduras	7	55,097	266,222	702,938	200,000
Nicaragua	4	76,575	398,460	150,000	136,000
Costa Rica	13	60,000	377,500	n/a	58,000
Panamá	4	43,000	270,000	n/a	30,000

Source: Adapted from (Asociación Azucarera Salvadoreña 2020; Azúcar de Guatemala 2020; Comité Nacional de Productores de Azúcar de Nicaragua 2020; Asociación de Productores de Azúcar de Honduras 2020; Liga Agrícola Industrial de la Caña de Azúcar de Costa Rica 2020)

Regarding their social and environmental approaches, most of the sugar mills present on their website, different actions, programs, and initiatives to deal with environmental issues. Some of them include declarations and commitments to the SDG's, as shown in Table 6

Table 6: Main activities declared by sugar mills as part of their social and environmental responsibility

Social Activities	Environmental Activities	Others
Zero child labor tolerance	Ashes are used as fertilizers	Signature of ODS commitment by sector
Salaries are pay according to local laws	Used water from process as fertilizer	Memory of environmental indicators
Economic fund for local schools	Bagasse is used as renewable fuel for boiler	Respect to local limits of emissions
Water Supply and alimentation of workers in fields	Reuse of water in circuits inside sugar mill to reduce exhaust and vapor released	
Transport	Molasses are used to produce carburant alcohol as substitute of fossil fuel	
	Fertilizes (N,P,K,S)	

Despite those benefits, the very processes of harvest and sugar mill indeed present several technical challenges with impact in the environment, is the intensive use of land and water, the use of nitrogen-based fertilizers, and the emissions to air of particulates, CO2, SO2, N2, P2 some of the main fluxes generally not considered even in the memories of environmental actions taken by the industries. The question about how this industry is considering the new circular economy trends and how it is located within its sectors become valid questioning that must be addressed; it is necessary to quantify the impacts to have a clear idea of their contribution to global and local environmental challenges.

2.3. Circular Economy Framework

Circular Economy Framework is a strategy aimed to reduce the use of materials as well as the waste and residues in any product or service industry, closing the economic and environmental loops among interrelated sectors (The Ellen MacArthur Foundation 2020).

The principles stated are similar to the discipline of Industrial Ecology, focused on product design and manufacturing process to reduce materials and energy having a biological analogy to ecology, where all resources are recycled within interrelated parties, using practically all the resources in closed loops. Industrial Ecology relay on different technical approaches such as systemic Analysis (resource studies with Material Flow Analysis and social and economic studies) and Eco-design principles such as Life Cycle Thinking, dematerialization, and decarbonization (Ayres and Ayres 2002). Industrial Ecology and Circular Economy have similar objectives, but different tools to get to them.

The best exponent of Circular Economy (CE) is found in the Ellen McArthur Foundation, where it is clearly stated the three principles of CE..

- Design out waste and pollution
- Keep product and materials in use
- Regenerate natural systems

The system diagrams in figure 3 shows the continuous flows of technical and biological materials

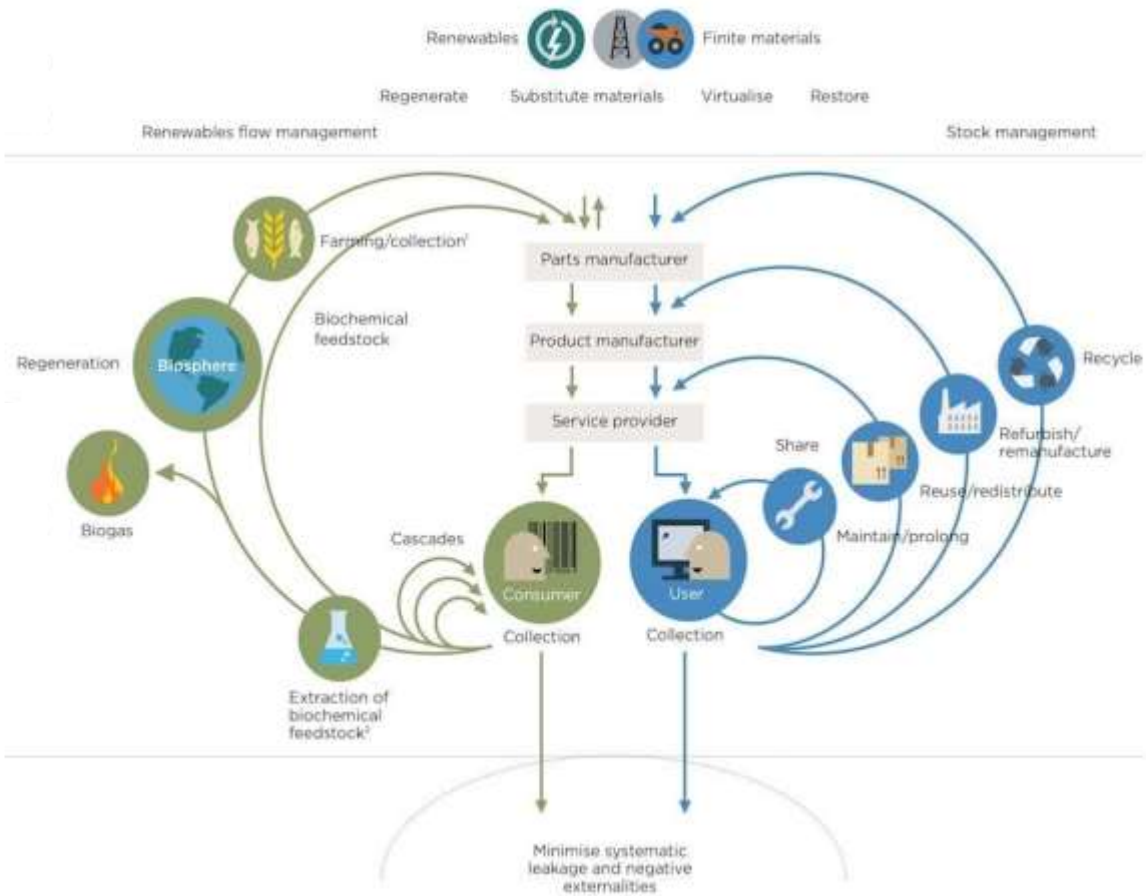

Figure 3; Circular Economy Framework. Adapted from (The Ellen MacArthur Foundation 2020)

In the sugar industry, they belong to the farming/collection flow of materials coming from the biosphere, where they regenerate. At that level, it seems that the nature of the product itself is well placed among CE principles. However, the problem is that such industry relays on the intensive use of resources that follow mostly linear production systems, such as fossil fuels and derivates.

Circular Economy also suggests a hierarchy to address the shift from the waste management system to CE Hierarchy, as presented in figure 4. That should be the hierarchy to be used when considering the different resources and materials needed to produce sugar.

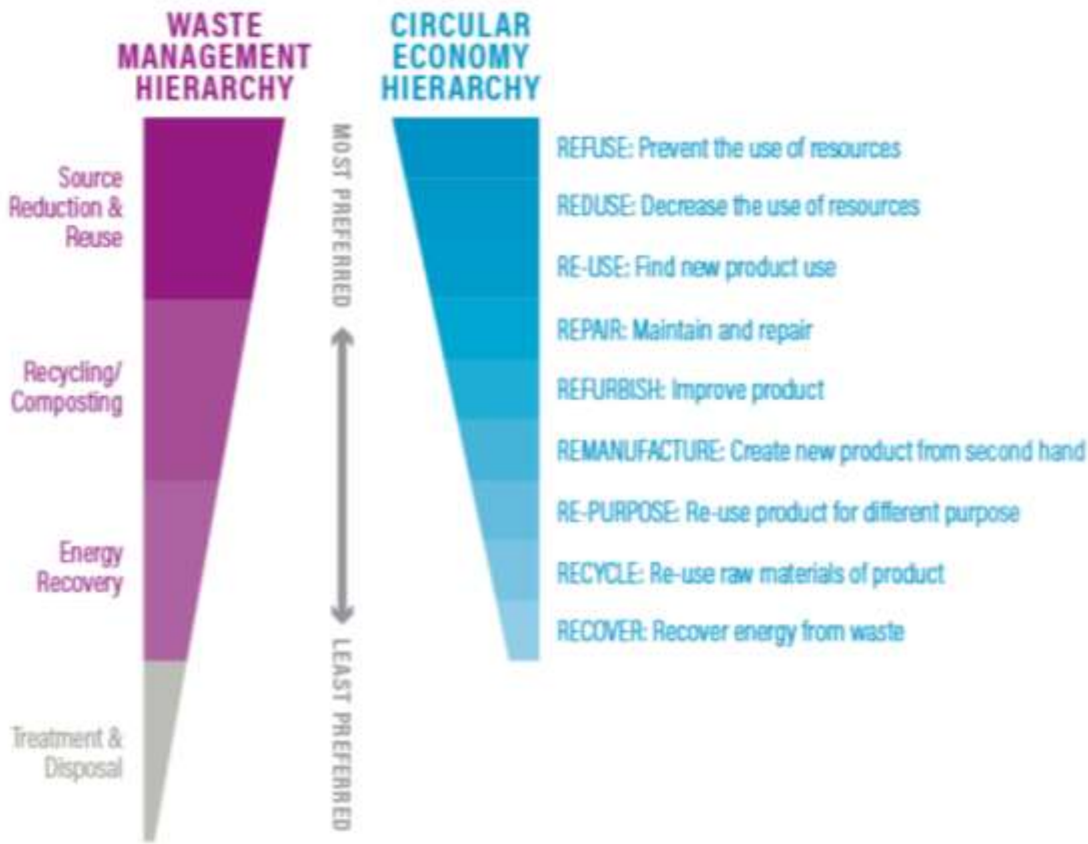

Figure 4: Circular Economy Hierarchy from (“World Resources Institute | Making Big Ideas Happen” 2020)

Along with this situation, it is noted that the very use of resources itself, and the effort to reduce their quantity sometimes could be misleading if the final environmental impacts are unknown. As a result, It is then necessary to quantify the fluxes of materials and energy of all the resources needed in the production of the sugar industry and to characterize and quantify the impacts to have a better understanding of the tradeoffs of any possible reduction or substitution..

3. Methods

In order to quantify, analyze, and compare how much the current industry is adapting the Circular Economy framework, it is proposed to use an archetypal impact characterization using Life Cycle Assessment (LCA).

Life Cycle Assessment is a structured, comprehensive, and international scientific method based on a standardized framework to assess a product and service(European Commission and Joint Research Centre 2010), as presented in figure 5::

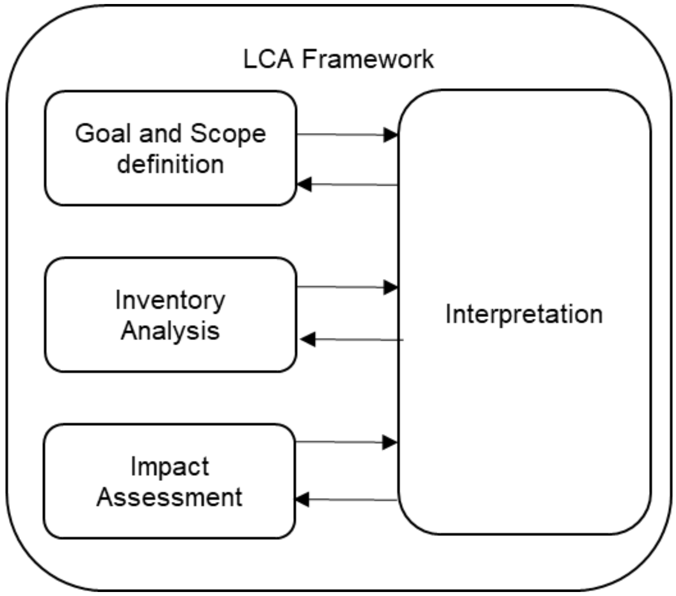

Figure 5: Basic stages of Life Cycle Assessment Framework. Adapted from (ISO 14044 2006)

Despite there are other stages, they are considered optional.

3.1. Life Cycle Assessment application

The functional unit is defined as the production of 1 ton of sugar harvested in central America.

3.1.1. Objective, Scope and Functional Unit

The LCA's objective is to represent an archetype product, considering their conditions such as technology, availability of local materials, transport, and distances, among others. To do so, specific modifications and adaptations were considered using the Agri-footprint database to produce 1 ton of sugar. Data coming from Brazil was taken due to the similarities in edaphoclimatic conditions as well as availability.

3.1.2. Life Cycle Inventory

Having the Agri-footprint database values, central America's specific conditions were then included to adapt the life cycle inventory. Specific changes made are provided as supplementary material of this paper. The inventory modeled a typical sugar mill in central America considering their average distances, type of agrochemical, fertilizers, flocculant, and other chemicals used either in the field or within the sugar mill..

3.1.3. Impact Evaluation

To characterize the environmental Impacts, ILCD 2011 Midpoint was chosen. The reasoning was that ILCD contains the environmental factors that can provide important insight for the sugar mill, including global warming potential, eutrophication, ecotoxicity, ozone depletion, and water depletion. SimaPro 9.0.0.46 by PRé Consultants was selected to run the LCA.

Despite ILCD 2011 presents 16 characterization factors, this paper will focus on a selection of factors. The selected factors and their unit of measure are presented in table 7:

Table 7: Impact Characterization selected from ILCD 2011 Method

Impact category	Acronym	Unit of Measure	
Climate change	GWP	kg CO2 eq	kilograms of carbon dioxide equivalent
Ozone depletion	ODP	kg CFC-11 eq	kilograms of trichlorofluoromethane equivalent
Human toxicity, cancer effects	HTCE	CTUh	comparative toxic units for human toxicity
Particulate matter	PM	kg PM2.5 eq	kilograms of particulate matter suspended of less than 2.5 microns
Acidification	AC	molc H+ eq	moles of Hydrogen ion equivalent
Terrestrial eutrophication	EUTT	molc N eq	moles of Nitrogen equivalent
Freshwater eutrophication	EUTF	kg P eq	kilograms of Phosphorus equivalent
Marine eutrophication	EUTM	kg N eq	kilograms of Nitrogen equivalent.
Land use	LU	kg C deficit	kg of Carbon deficit
Water resource depletion	WD	m3 water eq	cubic meters of water equivalent

1.1.1. Interpretation

Since the objectives of this paper are to evaluate the level of application of CE principles by the sugar industry, the interpretation of the impacts will be considered estimating the theoretical volume of the functional unit to the amount of sugar produced, in order to contrast the challenges faced and the possible action routes that could be taken..

3.2. Forecast of impact

The forecast of impact for the next years would be made considering the trend of sugarcane milled in central America. Externalities such as the Covid-19 pandemic will be considered adjusting the results under the hypothesis that the economic recession would impact the volume of commodities consumed worldwide.

$$SugarIndustry\ Impact\ Factor_i = Characterization\ Impact\ Factor_i * Annual\ production \quad (1)$$

4. Discussion of Results

4.1. LCA results

The result obtained by applying the LCA using central America adapted data from the Agri-Footprint database available in SimaPro. It was necessary to avoid the double-counting of impact. This consideration was taken into account since the LCA values from 1 Ton of Sugar already include the use of SugarCane, so to evaluate each stage, it was necessary to consider the following equation:

$$Sugar\ production\ Impacts\ (in\ Mill) = Sugar\ Impacts\ (Total) - Sugarcane\ Impacts\ (in\ farm) \quad (2)$$

After running the LCA, the result of the sugar cane production at the farm, the Mill process, and the final Sugar impacts (cumulative) are presented in table 8::

Table 8: Impact Characterization values per 1 ton using ILCD 2011 Method

Impact category	Unit of Measure	Sugar Cane	Mill	Sugar
GWP	kg CO2 eq	1767.160608	1772.18387	3539.344475
ODP	kg CFC-11 eq	7.95532E-06	2.8694E-06	1.08248E-05
HTCE	CTUh	9.87425E-06	-4.524E-07	9.42185E-06
PM	kg PM2.5 eq	0.149641227	0.31197026	0.461611486
AC	molc H+ eq	5.596654782	1.81922736	7.415882144
EUTT	molc N eq	24.18175293	2.9629512	27.14470413
EUTF	kg P eq	0.138741321	0.08538408	0.224125403
EUTM	kg N eq	17.14809127	-1.5761022	15.57198907
LU	kg C deficit	25432.33421	-3346.8731	22085.46112
WD	m3 water eq	0.094302941	0.04931321	0.143616155

The negative values presented in the cumulative result for the Mill must be interpreted with caution. However, they suggest that the milling process provides some environmental credits level, specifically to those characterization factors (Human Toxicity, Marine Eutrophication, and Land Use). Those credits come from the combined use of renewable biomass (bagasse) and the co-generation of electricity provided to the public grid, preventing the use of fossil fuels in equivalent quantity. (Central América does not have fossil fuels, 100% of their consumption come from abroad).

One way to better understand the tradeoffs and relative importance of the different impacts is by applying normalization. This procedure is made, having in mind that normalizations are not included within the ISO 14044 required stages. It is understood that it is not free of some error or bias. However, it is presented here just as a reference to having a standard unit of measure by applying normalization to sugar production. This alow to have another insight from each impact factor's effect, as shown in figure 6:

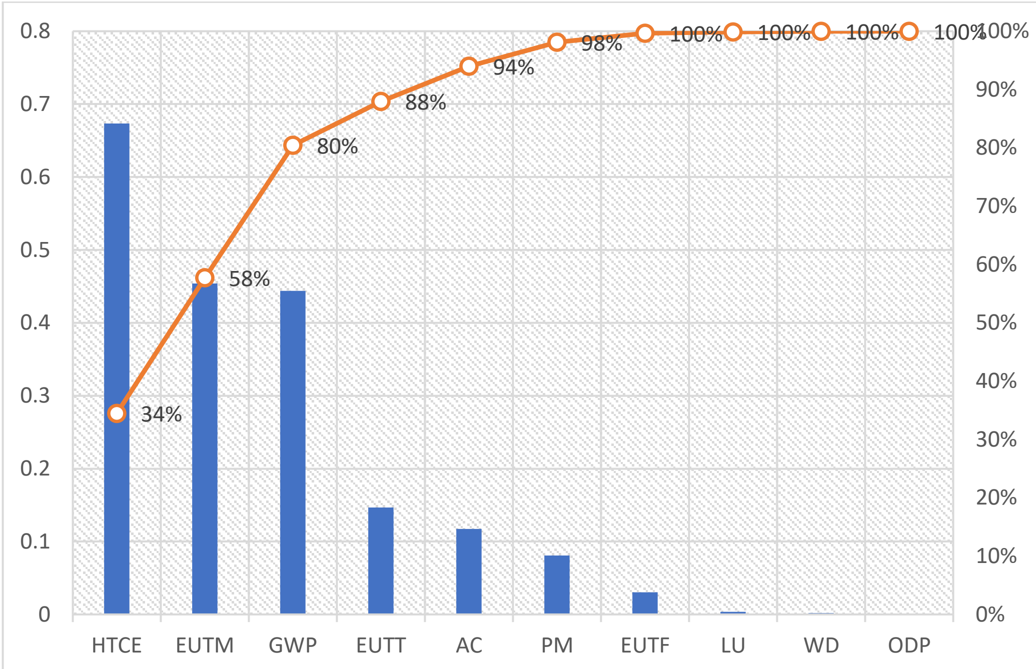

Figure 6: Normalized factors and Pareto Analysis

The main impacts for the industry relay in Human Toxicity-Cancer Effects (HTCE), Marine Eutrophication (EUTM), and Global Warming Potential impact (GWP). Using Pareto Analysis, those impacts account for 80% of the impact of this assessment.

The result and concentration on those three impact factors are explained considering that such crop requires Intensive occupation of land, heavy use of Nitrogen-based fertilizers (mostly derived from fossil fuel and imported to Central America), intensive use of agrochemicals (such as glyphosate), intensive use of fossil fuel for the logistic & transport of the harvested cane (usually using a fully loaded truck with low efficiency) among others.

4.2. Impact forecast

Considering those results, and focusing on the impact factors identified with the Pareto analysis, it is possible to have a forecast of the volume of the impact that could be expected for the next five years, as shown in Table 9

Table 9: LCA CO_2 eq. per country

Country	2018 CO2 Emissions (Tons of CO2 Eq)	Sugar Produced in zafra 2020 (Tons)	LCA Emission * Producción (Tons of CO2 Eq)	% of LCA Emissions /Emission per country
Guatemala	18,539,316	2,900,000	10,264,099	55.4%
El Salvador	6,853,766	750,000	2,654,508	38.7%
Honduras	9,320,279	266,222	942,252	10.1%

Nicaragua	5,325,447	398,460	1,410,288	26.5%
Costa Rica	8,328,890	377,500	1,336,103	16.0%
Panamá	11,599,764	270,000	955,623	8.2%
	59,967,462			

Source: adapted from (Global Carbon Atlas 2020) and LCA results

The comparison between the reported LCA CO2 eq. Per ton of sugar and the emissions are presented just as a reference, since LCA includes all the CO2 contained within the materials and energy. As has been stated, most of the fertilizers are fossil fuel derivates, some agrochemicals, and the very fossil fuel used during the transport.

The analysis reinforces two main finding:

1. It is needed to have more detailed data, that might include comprehensive referenced databases for sugar in every country.
2. This analysis was made just with CO2, but it is possible to estimate the rest of impact factors in the same way as presented in table 10, that summarizes the impact in the Central American Region

Table 10: Emission per zafra (2020 base)

Impact category	Unit of Measure	Guatemala	El Salvador	Honduras	Nicaragua	Costa Rica	Panamá
GWP	kg CO2 eq	1.03E+10	2.65E+09	9.42E+08	1.41E+09	1.34E+09	9.56E+08
ODP	kg CFC-11 eq	3.14E+01	8.12E+00	2.88E+00	4.31E+00	4.09E+00	2.92E+00
HTCE	CTUh	2.73E+01	7.07E+00	2.51E+00	3.75E+00	3.56E+00	2.54E+00
PM	kg PM2.5 eq	1.34E+06	3.46E+05	1.23E+05	1.84E+05	1.74E+05	1.25E+05
AC	molc H+ eq	2.15E+07	5.56E+06	1.97E+06	2.95E+06	2.80E+06	2.00E+06
EUTT	molc N eq	7.87E+07	2.04E+07	7.23E+06	1.08E+07	1.02E+07	7.33E+06
EUTF	kg P eq	6.50E+05	1.68E+05	5.97E+04	8.93E+04	8.46E+04	6.05E+04
EUTM	kg N eq	4.52E+07	1.17E+07	4.15E+06	6.20E+06	5.88E+06	4.20E+06
LU	kg C deficit	6.40E+10	1.66E+10	5.88E+09	8.80E+09	8.34E+09	5.96E+09
WD	m3 water eq	4.16E+05	1.08E+05	3.82E+04	5.72E+04	5.42E+04	3.88E+04

4.3. Sugar Industry and CE principles applied

The sugar industry has responded with its own way to address SDGs commitments and environment. Table 11 presents some actions and initiatives declared among the sugar mill factories (Asociación Azucarera Salvadoreña 2020; Azúcar de Guatemala 2020; Asociación de Productores de Azúcar de Honduras 2020; Liga Agrícola Industrial de la Caña de Azúcar de Costa Rica 2020; Comité Nacional de Productores de Azúcar de Nicaragua 2020) as environmental efforts to include the CE framework:

Table 11: Selected environmental actions compared with CE Hierarchy)

Environmental Actions:	Main Benefit	REFUSE	REDUSE	RE-USE	REPAIR	REFURBISH	REMANUFACTURE	RE-PURPOSE	RECYCLE	RECOVER
Use of Bagasse as renewable fuel for energy	reduces 100% the disposal of the bagasse as waste and generates electricity									◙
Use of "Cachaza" an organic residual as fertilizer	Returns nutrients and organic residuals to the fields in the agricultural cycle, reducing the use on nitrogen-based fertilizers		◙						◙	
Provide electricity to public grid	Energy provided reduces the use of fossil fuel		◙							
Install heat interchangers	Reduces the total amount of steam used in mill		◙							
Use mechanic clean instead of chemical clean	Reduces the amount of Chlorhydric Acid used in cleaning process		◙							
Use of electrostatic precipitators in boiler exhaust to collect ashes	Reduces particulates releases in atmosphere and collect ashes to be used as fertilizers		◙						◙	
Production of Molasses to produce Alcohol to be mixed with gasoline	Reduces the use of fossil fuels		◙							

Being REFUSE the most preferred stage of CE, and recovery the least preferred stage, it is noticed that the sugar industry indeed has work to reduce the consumption of resources. However, there is plenty of room available to try to REFUSE, especially in the agrochemical and fossil fuel area. An effort focused on those materials could not only increase the application of CE principles, but it is also related to the highest environmental impacts identified in the LCA case: Human toxicity and marine eutrophication.

5. Conclusions

This study presented a general panorama of the sugar industry in central America and their efforts to be more environmentally friendly. The results show that the sugar industry's contributions play a relevant role in the central American economies; therefore, the industry will remain one of the critical sectors for governments to generate employees in their countries.

The life cycle Assessment performed highlights the importance of quantifying the impacts to know how to focus on the issues or hotspots. The percentage of emission of CO2 is an example of such highlight: Despite the results for the emissions of CO2 are just for reference -since a lot of that CO2 contained is imported to Central America within the materials- the same results already provide valuable insight as what would it be the focus, considering the declared emission per country and the contribution.

Current trends in the environmental declaration are considered a suitable tool for the sugar industry to improve environmental performance. Since Environmental Product Declarations (EPD) are LCA-based, this could better understand their environmental impacts. As a result, they could reduce their impacts with a better understanding of their activity level and its consequences.

The percentage of emissions presented in table 9 surpasses the percentage of contribution to the GDP presented in table 1. This indicates that the sugar industry has a very intensive usage of higher resources than their contribution to the environment. Even though the results might not be equally comparable, this insight is also supported by the process analysis where fossil fuel, fertilizers, water, and others are indicated.

Circular Economy has been presented as a revolutionary way to re-think companies, and LCA can help to build more robust Circular Economy Studies (Life Cycle Initiative 2020). It might have great potential to reduce environmental burdens within the manufacturing sector. However, regarding the agricultural sector -designed to work in a classic linear production scheme- would be harder to apply. Table 11 presented a list of selected environmental initiatives taken within the sugar industry, but it is noticed that there is still a long way to run.

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